

Nationwide Urban Runoff Program
Urban Runoff Control in
Rapid City, South Dakota: Executive Summary

Black Hills Council of Governments
Rapid City, SD

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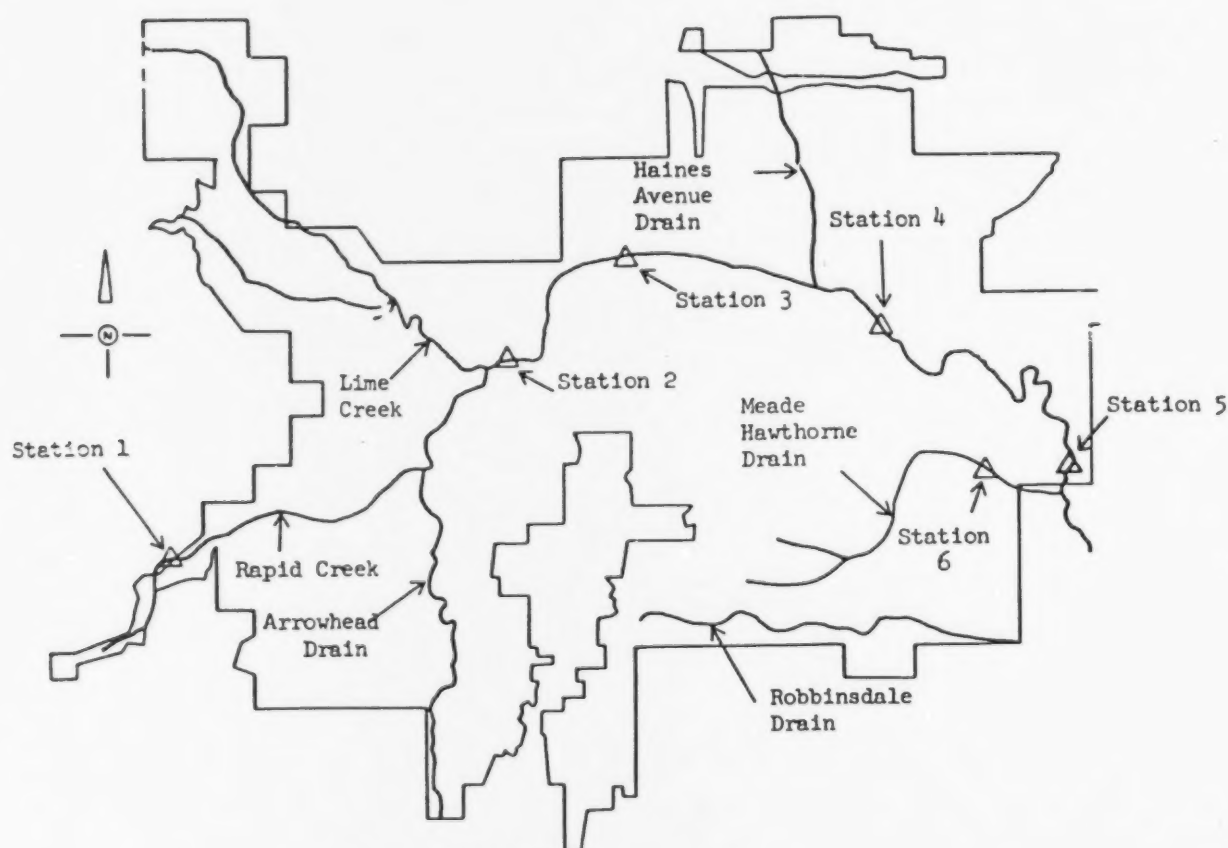
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URBAN RUNOFF CONTROL IN RAPID CITY, SOUTH DAKOTA

FINAL REPORT

SOUTH DAKOTA SCHOOL OF MINES & TECHNOLOGY

EXECUTIVE SUMMARY



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EXECUTIVE SUMMARY

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R A P I D C I T Y , S O U T H D A K O T A

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This summary condenses a two volume report submitted by Harms and Smith of the South Dakota School of Mines and Technology and Goddard of the United States Geological Survey. The original report consists of 101 pages of single spaced text, including 24 figures and 40 tables, and five appendices. The total report of 458 pages is available from Black Hills Council for the cost of reproduction. Each section in this summary corresponds to a section in the main report which has the same title and section number. The abstract and conclusions are identical to those found in the original report.

DEFINITIONS

BOD (Biochemical Oxygen Demand)

The amount of oxygen used by micro-organisms to stabilize a water or wastewater under aerobic conditions.

ALKALINITY

A measure of the buffering capacity of the water. It is the total of all components in the water which have a tendency to raise the pH above 4.5.

TURBIDITY

A measure of the particles which restrict the passage of light through the water.

pH

An expression of the hydrogenion activity in the water; in other words, the intensity of the acid or alkaline condition of the water. A pH of less than 7 means the solution is acidic. A pH of more than 7 means the solution is basic.

CONDUCTANCE

The ability of a water to carry an electrical current. Current is carried on dissolved ions, so a low conductance relates to a water with a small amount of dissolved solids.

COD (Chemical Oxygen Demand)

A measure of the total organics present in water.

FECAL COLIFORMS

A microorganism found in the gut of warm blooded animals. The identification of these organisms indicates the presence of fecal contamination and possible health hazards.

SUSPENDED SOLIDS

Suspended material in water which can be trapped on a filter.

VOLATILE SUSPENDED SOLIDS

The organic portion of the suspended solids.

TOTAL RESIDUE

The total amount of material in a water, both dissolved and suspended.

TOTAL KJELDAHL NITROGEN

The sum of organic-nitrogen and ammonia-nitrogen in water.

TOTAL PHOSPHORUS

The amount of phosphorus in water, both dissolved and associated with particulates.

SOLUBLE PHOSPHORUS

Phosphorus which is dissolved in water. The fraction of total phosphorus which is not tied up with particulate matter.

AMMONIA

The fraction of inorganic nitrogen which is in solution as either free ammonia, NH_3 or as the ammonium ion, NH_4^+ .

NITRATE

The fraction of the inorganic nitrogen which is in solution as nitrate, NO_3 .

SULFATE

A major anion in water, SO_4 .

CHLORIDE

A major anion in water, Cl , often associated with a common salt such as sodium chloride, NaCl .

POTASSIUM

A major cation in water, K .

SODIUM

A major cation in water, Na .

CALCIUM

A major cation in water, Ca , responsible for water hardness.

MAGNESIUM

A major cation in water, Mg , responsible with calcium for water hardness.

LEAD

The element lead, Pb , is toxic to humans and animals in small concentrations.

ABSTRACT

Six water quality sampling stations were installed to monitor water quality changes in Rapid Creek resulting from urban stormwater runoff in the Rapid City, South Dakota area. Five of the stations were in-stream locations on the creek while the sixth station was located on the drainage channel from a 2,000 acre watershed.

A total of 33 runoff events were monitored during 1980 to 1983, three of which were runoff from melting snow. Although some analyses of discrete samples were made, the norm was to composite the discrete samples in proportion to flow. Twenty complete data sets were obtained. Parameters measured included BOD, alkalinity, turbidity, pH, conductance, fecal coliforms, suspended solids, volatile suspended solids, total residue, total kjeldahl nitrogen, total and soluble phosphorus, ammonia, nitrate, sulfate, chloride, potassium, sodium, calcium, magnesium, and lead. All sampling sites were gaged by the United States Geological Survey for flow, and sophisticated sampling equipment was used at four locations during 1981 and 1982. Priority pollutants were determined at selected locations on three occasions. Precipitation for sampled events ranged from 0.08" to 2.99" and the urban discharge ranged from near zero to about 470 acre-feet.

Concentrations of in-stream constituents varied widely throughout the study, with the majority of the constituents increasing in concentration at the downstream stations. Increases of several thousand percent were noted for many parameters from above to below the urban area. High lead and suspended solids increases were particularly noticeable. It was noted that the municipal wastewater treatment facility would require about three years to deposit as many suspended solids in Rapid Creek as were washed into the creek in one day during storm event No. 21.

Many of the parameters correlate well with suspended solids concentrations. Therefore, the recommendation was made that remedial measures should concentrate on reducing the suspended solids loading to Rapid Creek.

ACKNOWLEDGEMENTS

Several different agencies were responsible for the conception, funding and implementation of this project. They are:

- (1) United States Geological Survey (USGS)
- (2) South Dakota Department of Water and Natural Resources
- (3) United States Environmental Protection Agency (EPA)
- (4) City of Rapid City
- (5) Black Hills Council of Local Governments
- (6) South Dakota School of Mines and Technology (SDSM&T)
- (7) South Dakota Department of Game, Fish and Parks

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I. INTRODUCTION

In the past, much of the nation's efforts to clean up its lakes and streams have been directed toward point sources such as industrial or municipal sewage discharges. Nonpoint sources, such as agricultural or urban drainage which occurs during a rainstorm, sometimes also cause pollution. Urban stormwater runoff is a nonpoint source which has the potential to cause water quality problems.

Urban runoff is typically of short duration and may contain substantial quantities of suspended material, dissolved solids, and bacteria from a variety of sources present on the urban watershed. Urban runoff is normally of poor quality and increases the concentrations of most constituents already present in the receiving water. Many streams do not meet water quality standards during storm runoff events.

As part of a national effort to understand urban runoff, a three year urban runoff study was conducted in Rapid City from January 1980 to December 1982. The water quality changes in Rapid Creek were the primary focus of the data collection efforts.

OBJECTIVES OF THE PROJECT WERE:

1. Characterize the impacts of urban runoff into Rapid Creek from both rainfall and snowmelt runoff; and
2. evaluate the effects of the runoff on a high quality, cold water fishery,
3. assess the value of in-stream water quality standards as related to water quality during storm events; and
4. assess the impact of urban runoff on downstream beneficial uses.

The information reported within this report deals chiefly with objectives 1, 3 and 4. The evaluation of the fishery, objective 2, was primarily the responsibility of the South Dakota Department of Game, Fish and Parks in conjunction with the South Dakota Department of Water and Natural Resources.

Previous studies have shown that a variety of constituents at varied concentrations are present in urban runoff. Oxygen demanding materials may exceed 1,000 mg/L, sediment concentrations over 5,000 mg/L are common, and nitrogen and phosphorus forms are normally reported as being several mg/L. Severe degradation of in-stream water quality has also been noted in many cases.

II. THE STUDY AREA

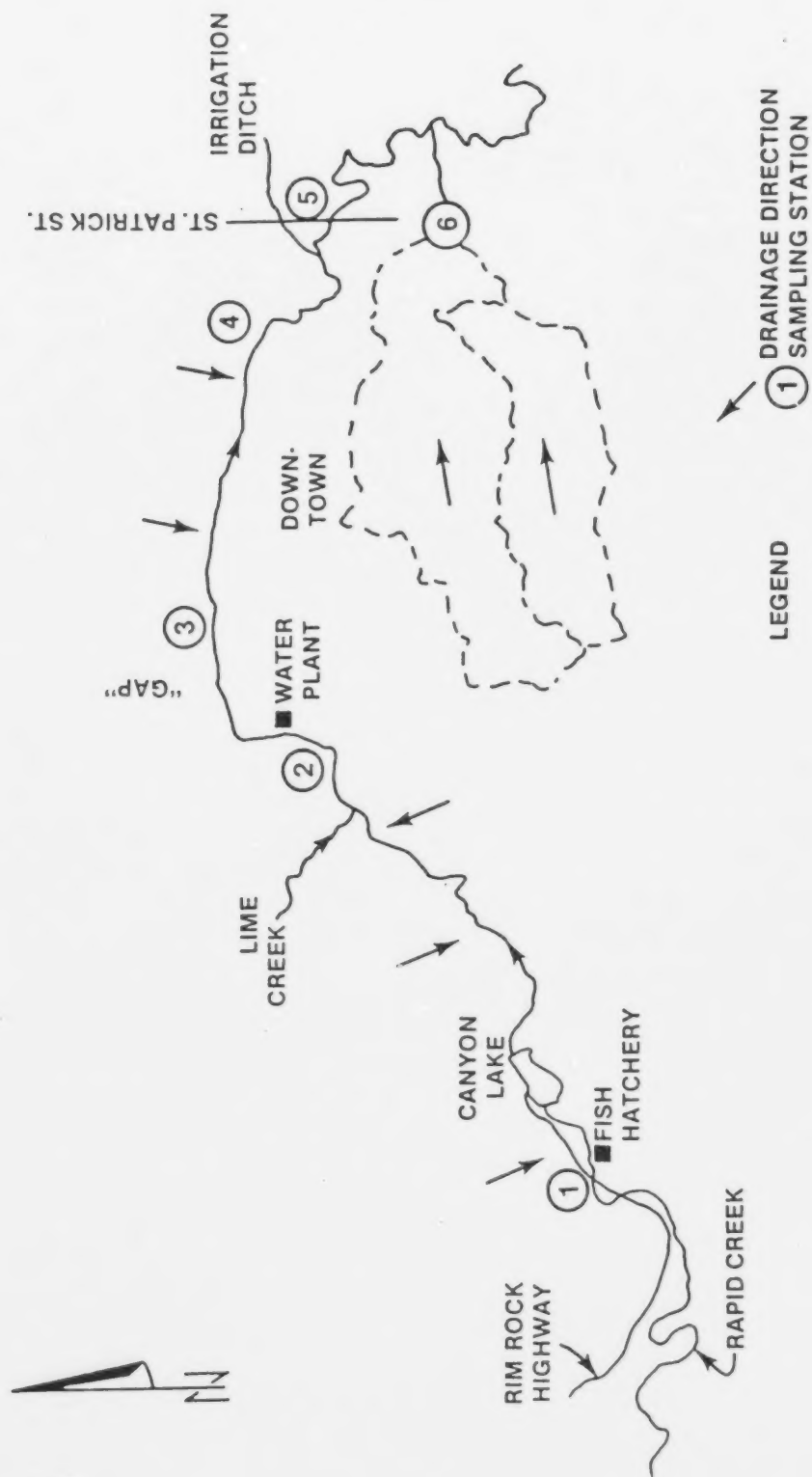
The study area lies within the physical boundaries of Rapid City, South Dakota. A vicinity map which shows the location of the six sampling stations is shown in Figure 1.

A description of each sampling station along with the justification for selection follows:

<u>Station No.</u>	<u>Description</u>	<u>Rationale</u>
1	Located at the USGS gaging station on Rapid Creek at west edge of Rapid City.	A background water quality station on the creek before the significant urbanization occurs. Data from samples at this station represents baseline conditions during a storm event. Comparing the data from this location with the rest of the data assists in determining the actual effects of the urban area.
2	Located on Rapid Creek at foot bridge in Sioux Park.	A station in the western part of town below some major urban discharges. Located below Lime Creek, but above the municipal water treatment plant.
3	Located on Creek at USGS gaging station near Black Hills Packing Company.	A station near the center of Rapid City. All the drainage from western Rapid City plus any drainage from the Cement Plant and quarries enter the creek prior to this station.

Station No.	Description	Rationale
4	Located on Rapid Creek at the East Main Bridge.	A sampling station just before the fairgrounds. The stream has begun to flatten out here, meanders are more frequent, and urban drainage from both the downtown area and North Rapid City are included in the stream flow.
5	Located on Rapid Creek at the St. Patrick Street bridge, just above the Meade St. drainage channel.	This sampling station was used to help determine the stream water quality as Rapid Creek exits the community. Sampling and mixing considerations made it more feasible to determine the quality below Rapid City theoretically by sampling above and on the Meade St. drainage.
6	Located on the Meade St. drainage channel	A station on the major urban drainage way to Rapid Creek. Some background water quality data was available for this drainage. The Meade St. drainage channel drains over 20 percent of the Rapid City land area. Data collected from this location reflected yield for the general range of pollutants that enter Rapid Creek from urban runoff. Data from Station 5 was used with data from this station to determine the stream water quality at the city limits. There is only minimal surface drainage between these two sites.

FIGURE 1. - MAP OF RAPID CREEK SHOWING LOCATIONS OF THE SIX SAMPLING STATIONS



To assist in data interpretation, land use categories of non-urban, urban-residential, rural-residential, commercial and industrial, and institutional were used. The non-urban use category was predominant for the land above sites No. 1, 2 and 3. Urban uses dominated for the other sites.

The annual average precipitation for the Rapid City area is about 18 inches per year. Most heavy snowfalls occur in early spring. Enough rainfall to cause runoff can be expected about 15 times each year.

III. FIELD TECHNICS

Samples were collected manually at all stations during 1980. In 1981 and 1982, four of the six sampling stations used automated sampling equipment. Manually collected samples were obtained by wading the stream and mixing representative portions from different depths and locations across the stream. Samples were collected during both normal flows without runoff and when precipitation caused runoff to occur.

Automated sample collection was directed by a pre-programmed microprocessor. Continuous discharge records were available from stage-discharge relationships. All of the automatic samplers were tested to determine if representative samples were being collected. It was concluded that the automatic samplers were collecting reasonably representative samples at all locations.

Field parameters measured were flow, dissolved oxygen, conductivity, pH, temperature, and atmospheric deposition. Special handling and sampling procedures were followed in obtaining three sets of priority pollutant samples during the project. For priority pollutant sampling, the automated devices were not used in order to avoid contamination.

IV. LABORATORY TECHNIQS

Samples were cooled in the field, and all remaining preparation and preservation were done in the laboratory. Individual samples were normally added according to flow into a single composite sample for each station for each event. A computer program was developed to determine the correct volume of each individual sample to be used.

A USGS cone splitter was used and evaluated to yield a compositing error of less than three per cent. A quality assurance plan was approved for use by EPA in order to insure the integrity of the data. Only approved laboratory procedures were followed.

Parameters measured were alkalinity, BOD, calcium, COD, chloride, ammonia, kjeldahl-nitrogen, nitrate, phosphorus, fecal coliforms, lead, magnesium, oil and grease, pH, potassium, sodium, specific conductance, sulfate, suspended solids, total residue and turbidity.

V. RESULTS

A theoretical location, identified as Station No. 56, was used to indicate in-stream data below Rapid City. Data for Station No. 56 were obtained by mixing the loads generated at Station No. 5 and No. 6. Data at Station No. 56 were compared to data from samples at Station No. 1, the up-stream background location.

Thirty-three runoff events, rainfall and snowmelt, were sampled over the three year period. In as much as possible, runoff events which would produce an increase in discharge at all six stations were sampled. Twenty complete sets of samples were obtained. Three of the events evaluated snowmelt runoff.

The streamflow in Rapid Creek is regulated by the discharge from Pactola Reservoir, increasing slightly as it flows through Rapid City because of additional flows from Cleghorn Springs, Lime Creek, and some artesian wells. The median discharge is 55 cfs at Station No. 1 and 65 cfs at Station No. 3. Mean monthly discharges vary from 12 to 135 cfs at Station No. 1, and from 28 to 156 cfs at Station No. 3.

Two long-term precipitation records for the Rapid City area give an annual average precipitation of about 18 inches. The majority of the precipitation occurs as rainfall between April and September, with June having the highest mean monthly value. Normally western Rapid City receives slightly more precipitation than the eastern edge of the City. Precipitation for sampled events ranged from 0.08" to 2.99".

A great deal of variability in both precipitation and runoff was noted across the study area. For example, storm event No. 20 had an average precipitation of 0.25 inches over the entire study area. The average rainfall over individual subbasins for this event varied from 0.09 to 0.94 inches. Each subbasin normally contributed a substantial discharge to the stream and the flow in the creek would continue to increase from Station No. 1 to Station No. 56. However, because of irregular precipitation patterns, sometimes almost all of the runoff would be generated on one or two subbasins. The volume of runoff from a subbasin divided by the

volume of precipitation which fell on the subbasin is the runoff: rainfall ratio. This is the runoff yield from a particular event. For this study the average runoff yield varied from 0.8 percent for western Rapid City to 1.15 percent for the Robbinsdale subbasin. The average runoff yield for the entire study area was 4.4 percent.

Runoff volumes were not determined for snowmelt events because accurate discharge data could not be obtained. In general, the water quality from snowmelt decreased as Rapid Creek progressed downstream with the poorest water quality peaking at Station No. 4. Some solids appear to settle out between Station No. 4 and 5. This material may become resuspended should higher flows occur. In-stream water quality standards are not met during snowmelt runoff.

Background values for all parameters during snowmelt runoff events were low, but normally increased in the urban area. Chlorides, for example, remained less than 4 mg/L at Station No. 1 while exceeding 100 mg/L at Station No. 4 and 5. Sodium shows a similar trend. Data have diurnal trends due to temperature influences on the amounts of melting snow. Snowmelt runoff events can result in gross contamination of the receiving watercourse as evidenced by suspended solids concentrations which exceeded values in untreated domestic sewage.

In order to assess the impact of pollutants entering the stream during runoff, conditions were also evaluated at normal flows. Even during normal dry weather flows, some degradation of Rapid Creek occurs as the stream moves through Rapid City. This degradation is evident in dissolved materials, suspended materials, and organics. In general, however, the baseline water quality in Rapid Creek is excellent in spite of some decrease in overall quality through the urban area.

Some discrete samples were tested throughout the duration of the storm for a few events. Responses in constituent concentrations with changes in discharge were normally the rule. Usually those parameters associated with suspended solids would closely follow the flow, increasing as flow increased and decreasing as flow decreased. Dissolved solids would

frequently reflect a dilution effect from the runoff water. The initial volume of runoff carries a somewhat higher sediment load than expected, thus giving a "first flush" action.

The undiluted event mean concentration (UEMC) was selected as the parameter to indicate the quality of runoff which entered the stream. The UEMCs were calculated by subtracting out baseflow loadings. The UEMC pointed out the magnitude of the loading from the Robbinsdale watershed. Clearly the sediment along with those materials tied to the sediment, which enters Rapid Creek during runoff events is a major source of water pollution. The size of the problem can be seen by the simple comparison presented in Table 1. At normal flows the average suspended solids concentrations at Station No. 1 and 56 were 4 mg/L and 13 mg/L, respectively; while during storm events the average concentrations were 22 mg/L and 1,038 mg/L. A substantial portion of the increase was due to the Robbinsdale watershed which had an average UEMC for suspended solids of 2,443 mg/L. On the average, the in-stream concentration of suspended solids nearly doubled after the Robbinsdale discharge enters the creek. Average suspended solids found in untreated sewage are about 200 mg/L.

TABLE 1

A comparison of suspended solids during normal flows and during runoff events.

Station No.	Average Suspended Solids Normal Flows (mg/L)	Average Suspended Solids Storm Flows (mg/L)
1	4	22
2	6	289
3	8	350
4	18	693
5	13	595
6	14	2,443
56	13	1,038

The UEMC was also used to calculate runoff loads. A dramatic increase in median runoff loads across Rapid City was noted, particularly in those constituents associated with suspended material. Lead, which was almost entirely particulate lead, showed a median increase of 104,000 percent between Station No. 1 and Station No. 56. Other major increases were in organics (24,400 percent), chloride (12,900 percent), phosphorus (14,000 percent), and suspended solids (63,500 percent). The lowest increase was for ammonia which still had an increase of 633 percent. All increases stated above are median increases, not maximum values.

An important problem when considering urban runoff loads is that the load is deposited in a relatively short time. One measure of an acceptable loading rate is to compare to the approved load which enters Rapid Creek from the municipal wastewater treatment plant. Organics and nutrients from urban runoff do not appear to cause excessive loading rates when compared to the treated wastewater effluent. However, the suspended solids load can be extreme. It would take three months for the treatment plant to discharge the same amount of solids that a moderate storm event would cause to be washed into the creek. It would take almost three years for the treatment plant effluent to contribute solids equal to those deposited in Rapid Creek in one day by a 2.5 inch rainstorm.

Initially it was thought that good correlations could be established which would relate rainfall to runoff, runoff to streamflow, streamflow to suspended solids, and suspended solids to other parameters associated with the solids. Good correlations for these relationships did not develop, primarily because a good relationship between streamflow and suspended solids did not occur. A relationship is evident; but not a predictable or simple one.

Most of the metals data was deleted because of questionable laboratory data obtained from the contract laboratory. The exception was lead, which was determined by SDSM&T. High lead values were found in-stream, but any water treatment process would normally remove these values. The remainder of the 127 priority pollutants tested were usually found to have a lower concentration than could be detected.

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Data obtained in the study were compared to allowable values as defined in the South Dakota water quality standards. The standards were violated on a regular basis, especially standards for suspended solids and fecal coliforms. It is difficult to evaluate the importance of these violations because information which evaluates these levels under dynamic, shock loading conditions are not available.

VI. SUMMARY

Sampling of urban runoff was conducted for three years on five in-stream stations and one major watershed. A theoretical station, No. 56, was used to indicate the in-stream conditions in Rapid Creek below the urban area.

The water quality in Rapid Creek is significantly degraded during urban runoff events. Most of the water quality parameters studied increased in concentration at the downstream locations.

Many variables were recognized as contributing to the water quality changes in Rapid Creek including intensity of rainfall, land use, amount of precipitation, and watershed characteristics. This study did not attempt to partition these variables and readily available relationships to water quality changes were not apparent.

Good estimates of rainfall: runoff responses and the resulting water quality can be made from the data collected. However, it is not possible to quantify the in-stream water quality from precipitation data alone. Even with the quantity of data collected under this project and the site specific hydrologic data obtained, the natural variations in the ecosystem preclude such simplistic predictions on such a complex system. Those interested in water quality should be able to make reasonable predictions of changes in Rapid Creek from urban runoff with the data presented in the overall report. High correlations of several constituents were obtained when compared to suspended solids. Because the suspended solids test is convenient and expedient, firm estimates of some other loads could be obtained using flow information and the suspended solids test.

The major source of much of the material contributed to Rapid Creek from urban runoff discharges is the Robbinsdale subbasin. This subbasin is the major source of pollutants to Rapid Creek. All other drainages empty into the creek prior to Station No. 5. When compared to the urban runoff load in creek Station No. 5, the Robbinsdale subbasin usually adds another 50 percent or more of the following constituents: chemical

oxygen demand, total kjeldahl nitrogen, lead, nitrate, phosphorus, suspended solids, volatile suspended solids, and total solids. In fact, the median suspended solids load to the creek from all urban drainage other than the Robbinsdale subbasin is 46,026 lb.; while the Robbinsdale subbasin alone adds a median suspended solids load of 61,646 lb..

VII. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn from this investigation:

1. Urban runoff causes significant water quality degradation of Rapid Creek during runoff events which are a result of rainfall and melting snow.
2. The water quality of Rapid Creek is degraded as it proceeds through the urban area even during normal low-flow conditions when runoff is not a consideration.
3. In-stream water quality standards are not met when wet weather discharges enter Rapid Creek.
4. The major pollutants are sediment and those constituents associated with the sediment load.
5. Based on the limited data gathered in this study, the only significant priority pollutant is lead. Other toxic materials do not appear to be a major problem.
6. It normally takes about 0.15" to 0.20" of precipitation to cause measurable runoff. This amount of rainfall can be expected to occur about 15 times each year.
7. The drainage from the Robbinsdale subbasin is the major source of the urban runoff loading to Rapid Creek.
8. As defined in this report a "first-flush" situation occurs on the Robbinsdale watershed.
9. Water purveyors should exercise caution when securing drinking water from Rapid Creek during wet weather conditions. Known toxics, such as lead, are known to exceed accepted health standards but are currently thought to be removed during water treatment.

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10. Firm estimates of COD and total phosphorus concentrations can be obtained from suspended solids values.
11. The runoff/rainfall ratio for the Rapid City urban area ranges from 0.008 to 0.115 with a mean ratio of 0.044.
12. High in-stream concentrations of dissolved constituents, especially sodium and chloride, are evident during snowmelt runoff.
13. The UEMC is an acceptable parameter for measuring the urban runoff load while sampling at a station which receives a base flow.

Recommendations are:

1. The City of Rapid City should find an alternate location for disposal of snow removed from streets. Currently this snow is piled adjacent to Rapid Creek and is an unnecessary source of pollution for the creek.
2. Any attempt to decrease the runoff load to the creek should emphasize the removal of suspended material. Removing suspended solids will also substantially decrease other major pollutants.
3. Remedial measures to reduce the urban runoff load should begin on the Robbinsdale watershed.